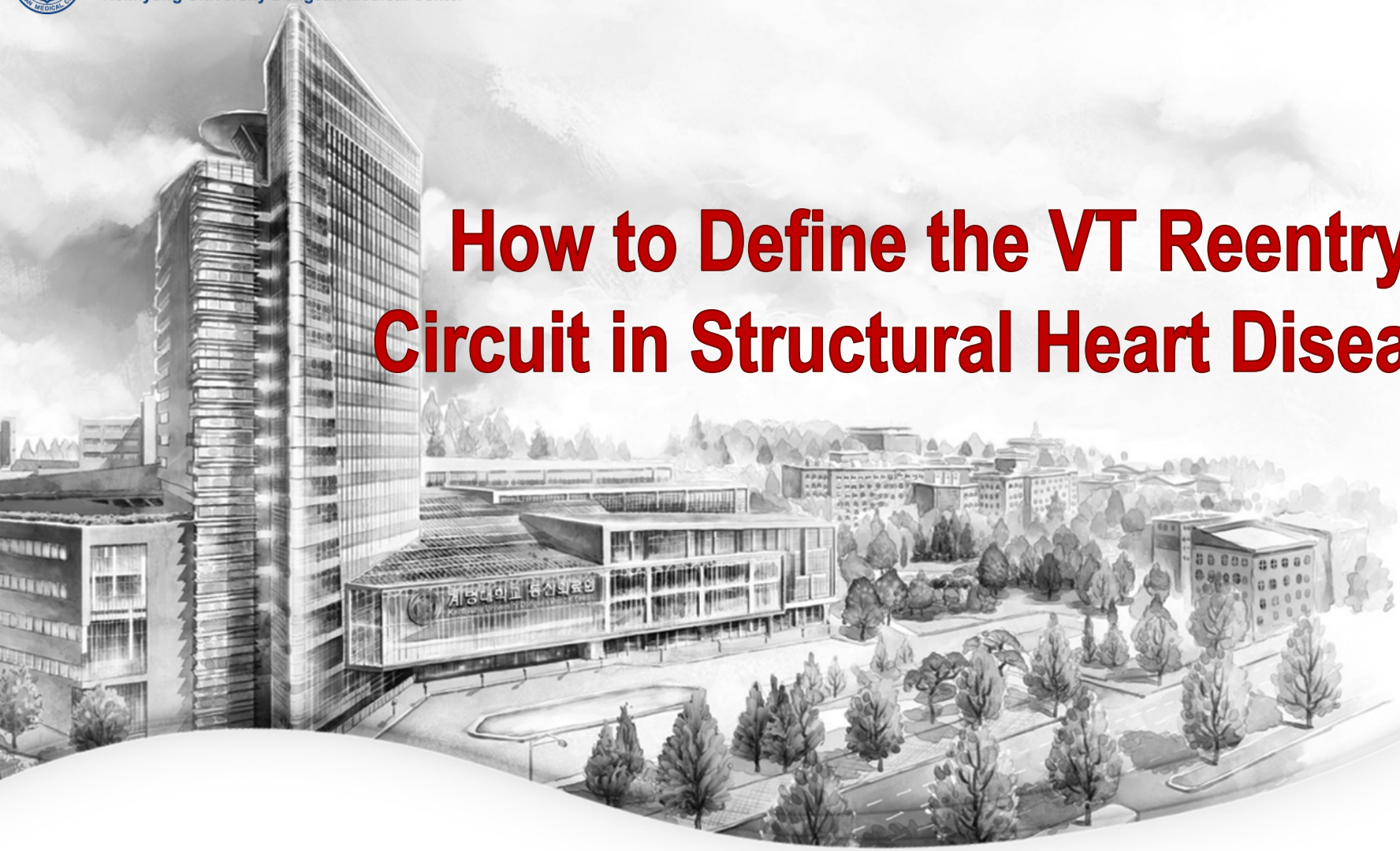
# How to Define the VT Reentry Circuit in Structural Heart Disease



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개원100주년기념
치유정원
VT
VT
VT

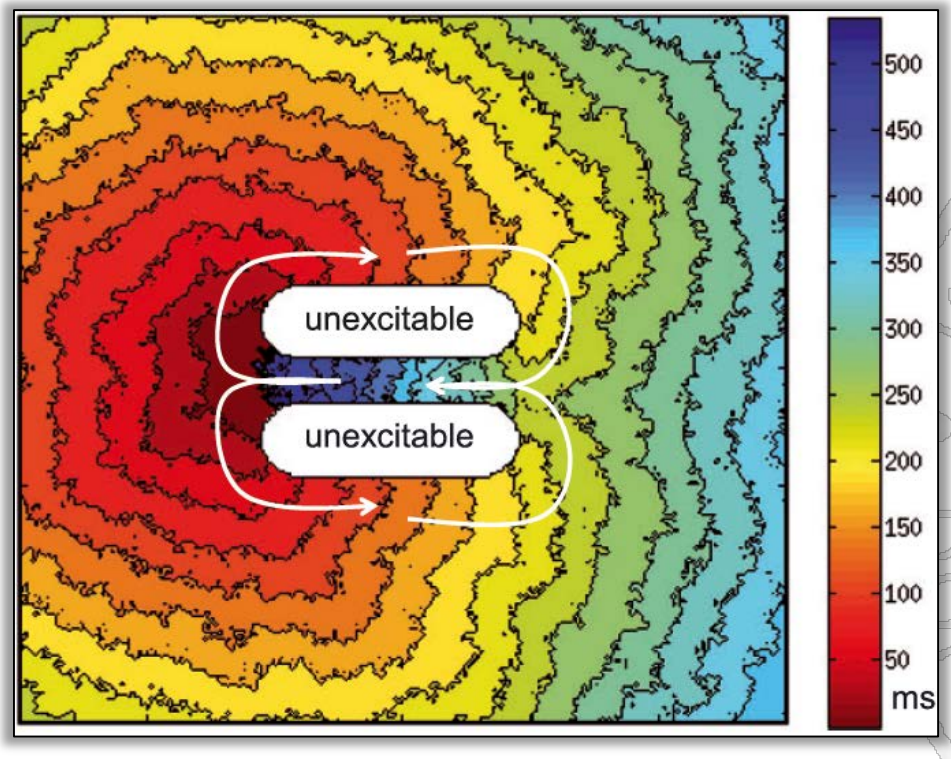
# How to define the reentry circuit of VT

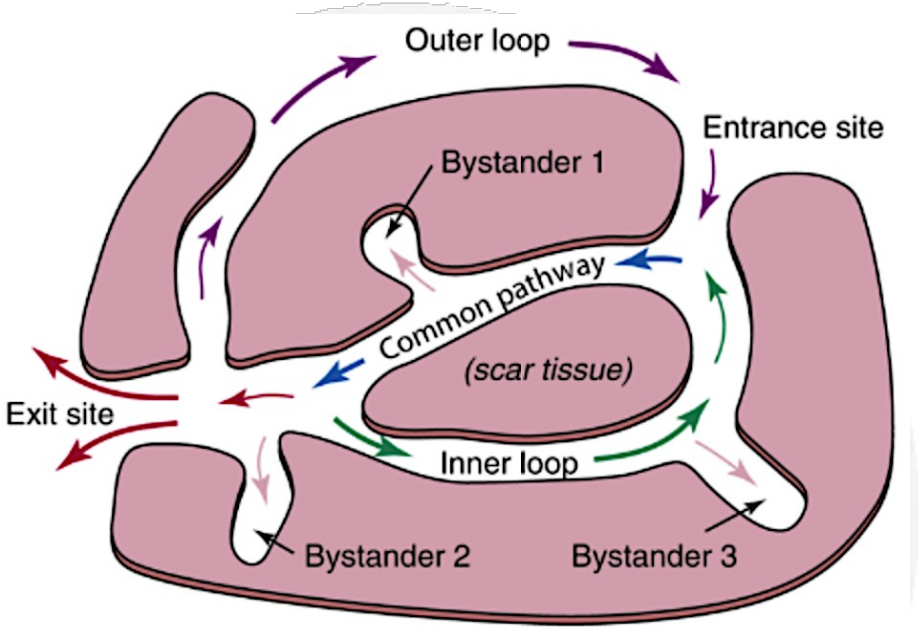
1. Detailed history taking of *past medical history*: MI, surgery, heart failure, family history, etc
2. Localization by *surface ECG of VT*
3. Localization by *cardiac imaging*
4. Electrophysiologic study
   - ✓ *Substrate mapping*: abnormal signals @ sinus rhythm
   - ✓ *Activation mapping* & *entrainment mapping*
   - ✓ *Pacemapping* during sinus rhythm based on substrate mapping

# Mechanism of Scar Related VT

- *Reentry*: VT associated with healed or healing MI in > *95 %*
- Originates from *surviving bundles of myocardium within the scar, separated by connective tissue, fibrosis and disordered intercellular coupling*
- Substrate develops gradually *during the first 2 weeks following MI* and once established, remains indefinitely

# Figure of 8 reentry



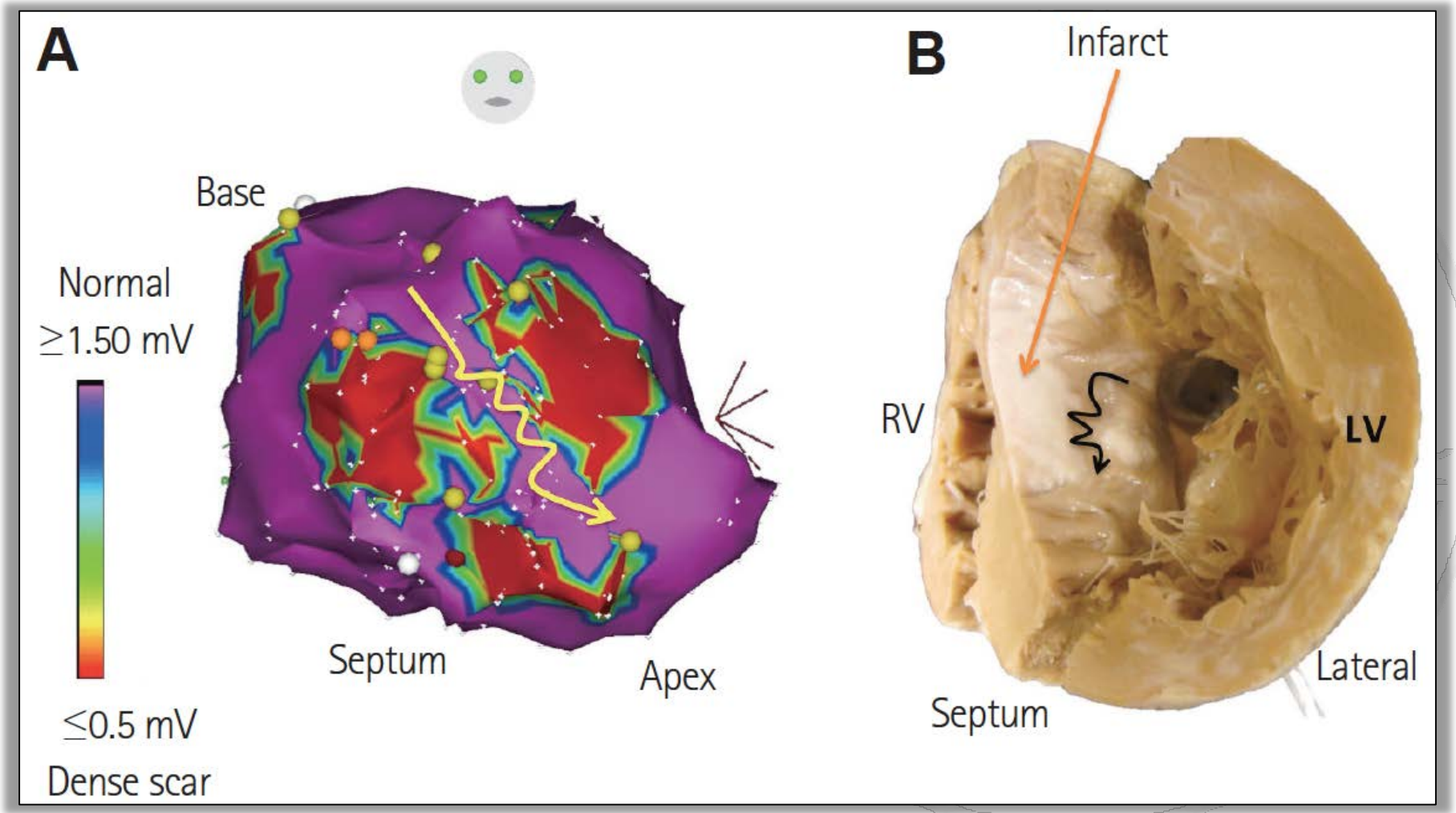




**Anatomical labyrinth circuit**, created by strands of viable myocardium within the scar, with *potential for multiple reentry circuits*



*Almendral J, et al. PACE 2013; 36:508*

# Substrate of Scar related VT

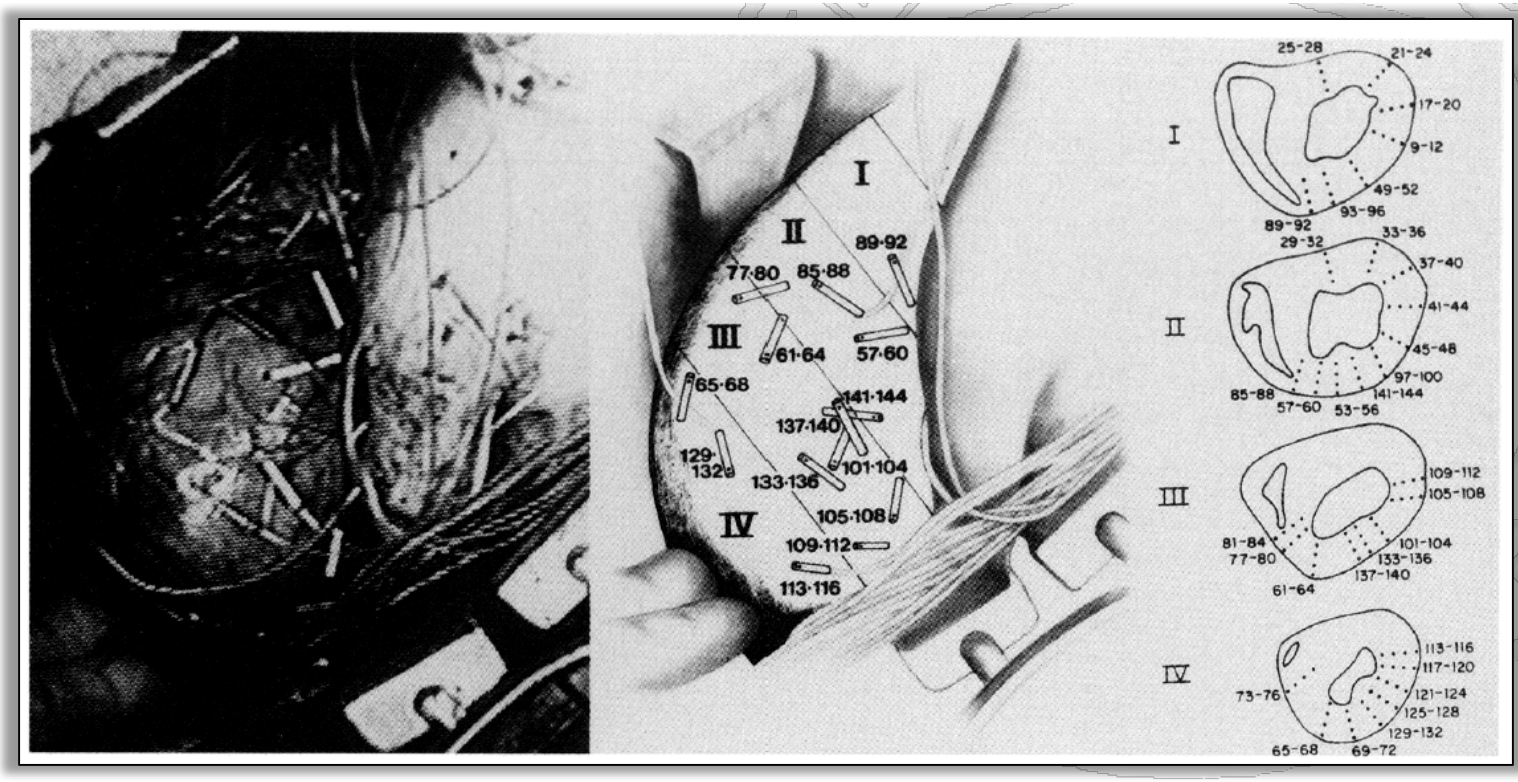





Nazer B & Gestenfeld EP. Korean Circ J 2014;44:201

# Reentrant and Focal Mechanisms Underlying Ventricular Tachycardia in the Human Heart

- Enrolled 13 patients with *healed MI & refractory VT*
- *10 VTs* in 8 patients were mappable with *plunge needle electrodes (39 needles; 156 intramural recording sites)*

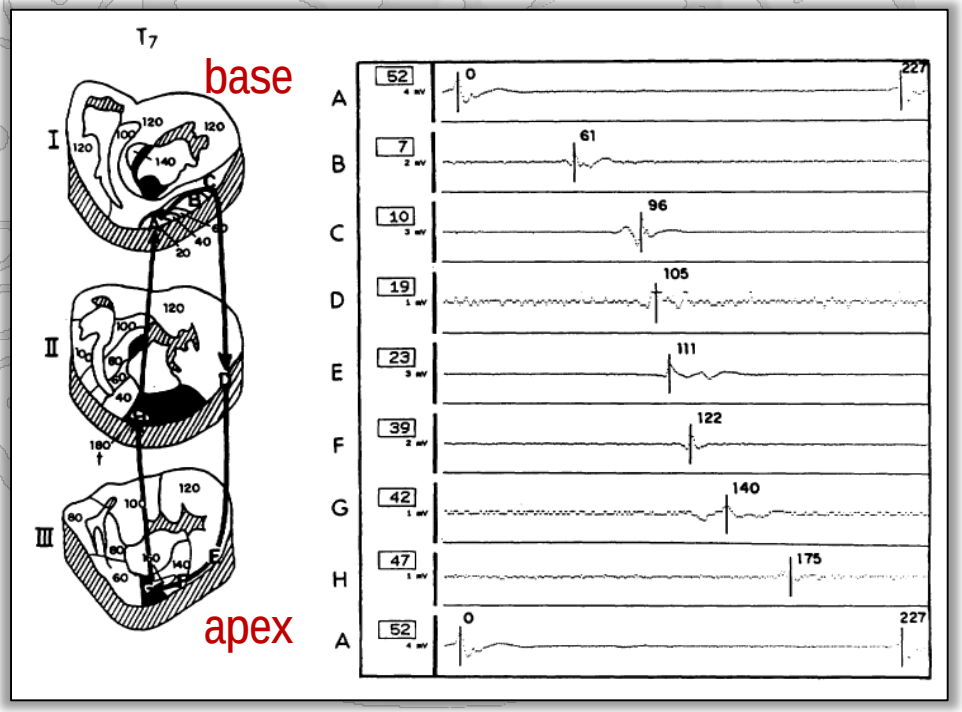





Pogwizd SM et al. Circ 1992;86:1872

# Reentrant and Focal Mechanisms Underlying Ventricular Tachycardia in the Human Heart

- 5 of 10 VTs (50%) were *reentrant sustained VT*: initiated in subendocardium or epicardium by *intramural reentry*
- Functional and anatomic *block were prominent* in the *subendocardium & midmyocardium*
- *Multiple simultaneous circuits* can be present



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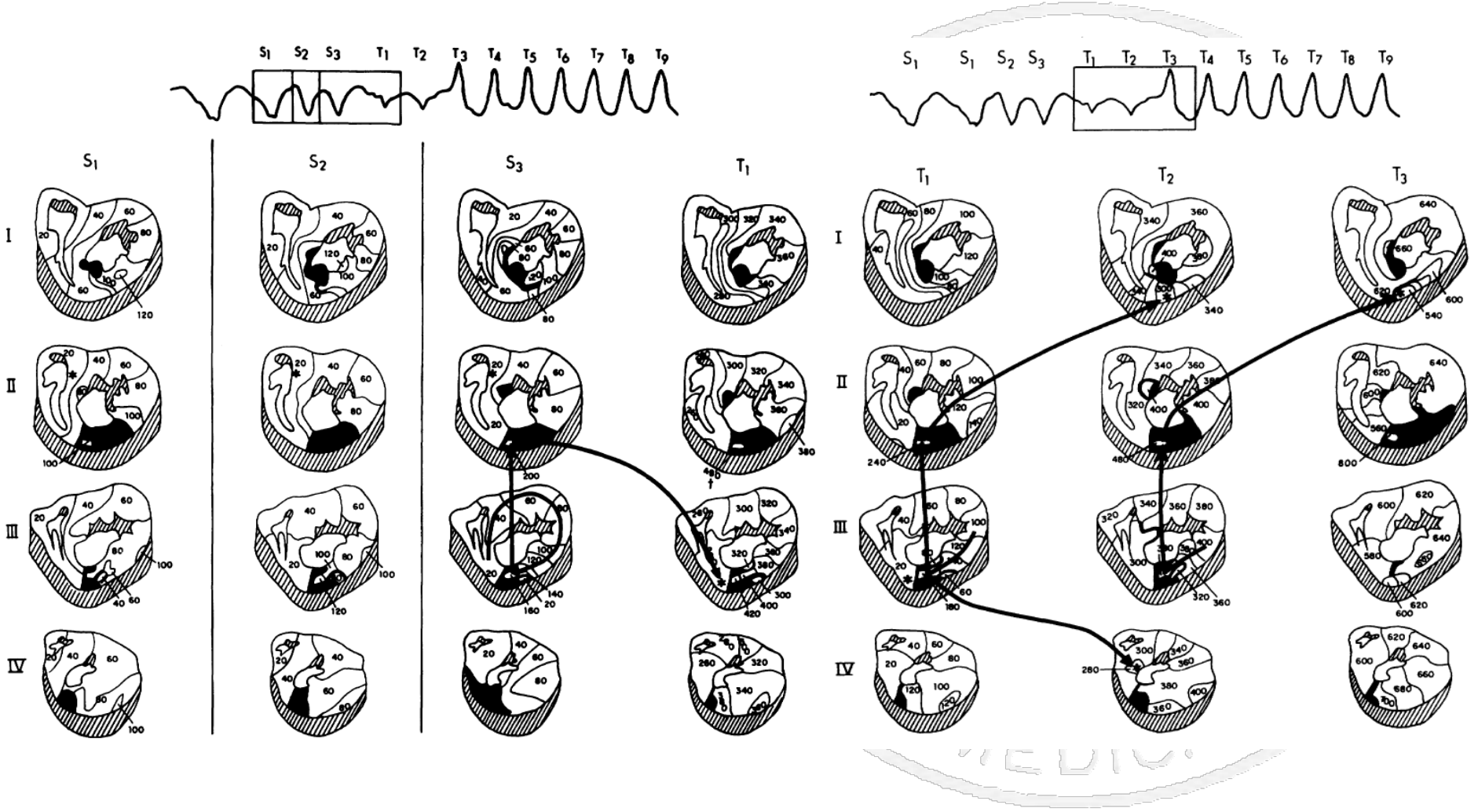
# Reentrant and Focal Mechanisms Underlying Ventricular Tachycardia in the Human Heart



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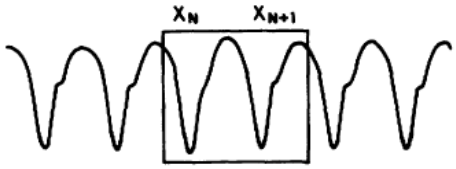
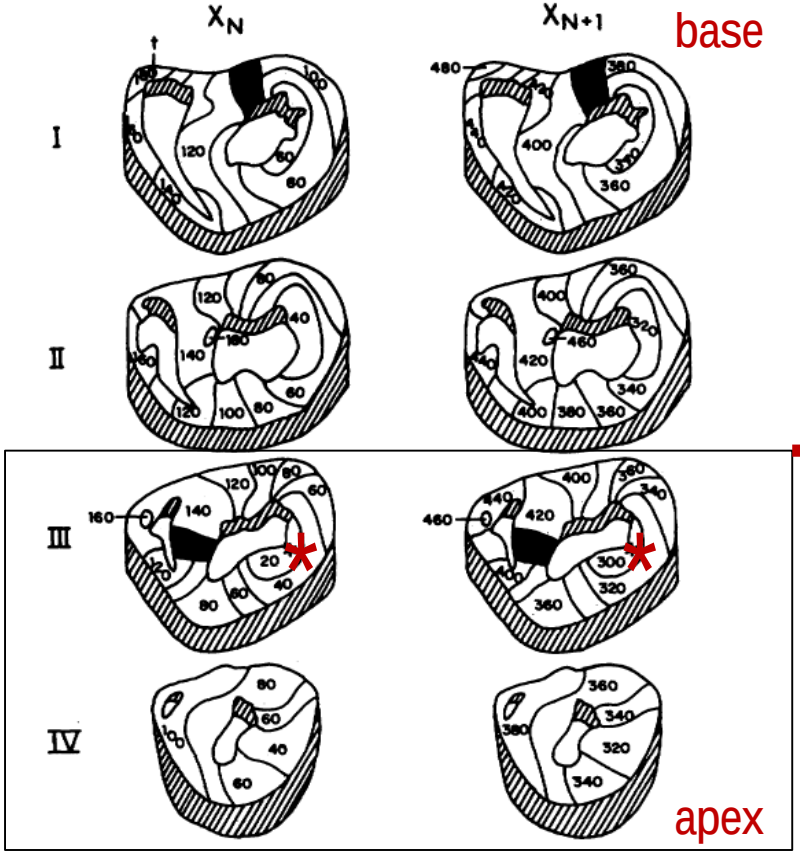
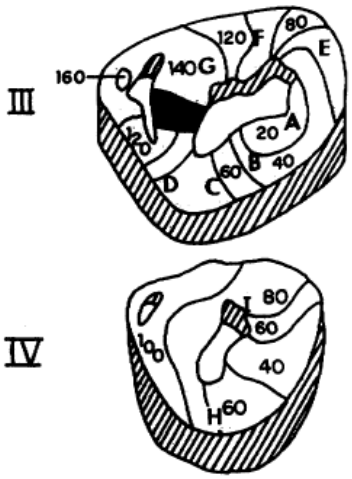
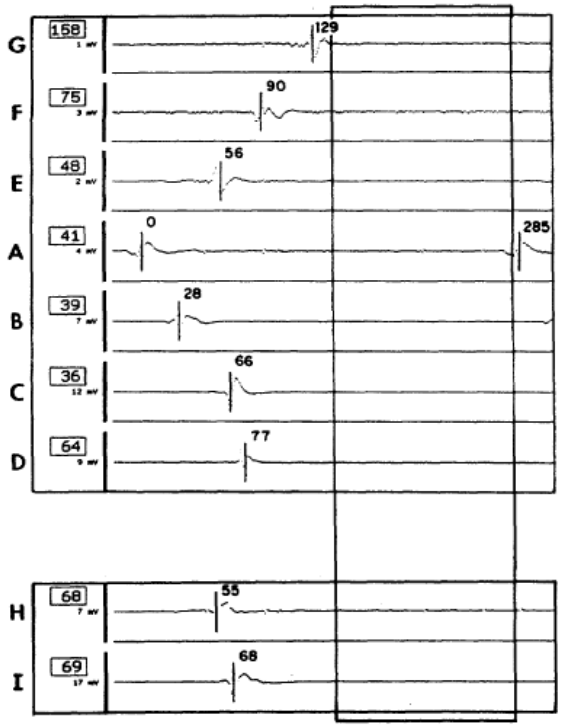
# Reentrant and Focal Mechanisms Underlying Ventricular Tachycardia in the Human Heart




❖ 5 of 10 VTs (50%) were *focal VT*



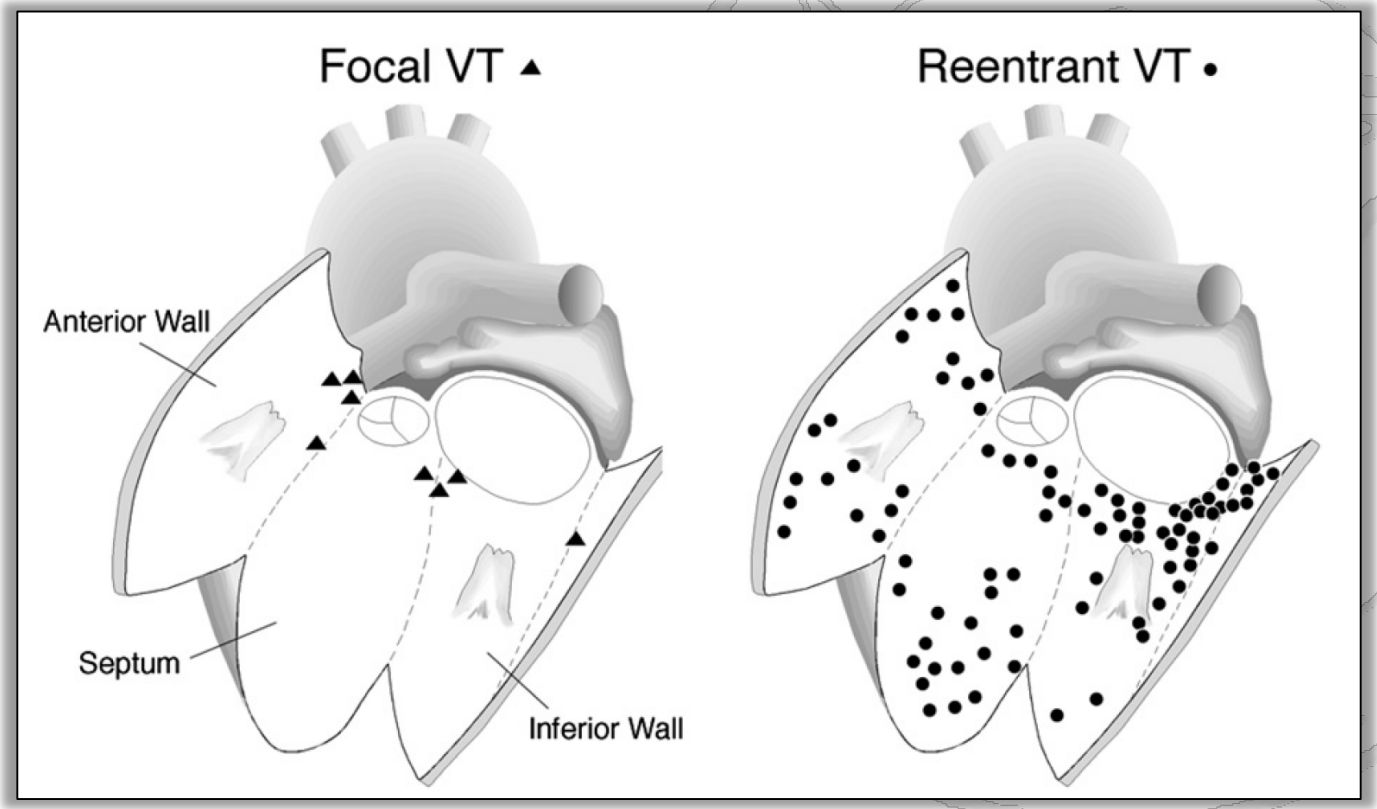






Pogwizd SM et al. Circ 1992;86:1872

# Focal mechanism of ventricular tachycardia in coronary artery disease

- 46 patients with prior MI
- 101 VTs: *focal 9%* (9) vs. *reentry 91%* (92)






Das MK, et al. Heart Rhythm 2010;7:305

# How to define the reentry circuit of VT

1. Detailed history taking of *past medical history*: MI, surgery, heart failure, family history, etc
2. Localization by *surface ECG of VT*
3. Localization by *cardiac imaging*
4. Electrophysiologic study
   - ✓ *Substrate mapping*: abnormal signals @ sinus rhythm
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   - ✓ *Pacemapping* during sinus rhythm based on substrate mapping

# General Principles

- Cardiac site at the time of *QRS onset*: *exit site from a VT circuit in reentrant tachycardia*
- **Exit site** or region from a VT circuit is typically *wider than the diastolic isthmus* (which may be >1 cm away)
- QRS morphology of VT
  - can **not direct to the actual ideal ablation target itself**
  - *serve as a guide as to where initial mapping effort should be directed*



Miller JM, et al. Card Electrophysiol Clin 9 (2017) 1

# General Principles

- *RBBB pattern VT (RBVT):*
  - ✓ The *latter portion of QRS in lead $V_1$ being a positive deflection*
  - ✓ Exit from LV in patients with/without SHD (structural heart disease)
- *LBBB pattern VT (LBVT):*
  - ✓ The *latter portion of QRS in lead $V_1$ being a negative deflection*
  - ✓ Without SHD: *from RV*
  - ✓ With SHD (common form): *from LV* (septum of < 1cm paraseptal



Miller JM, et al. Card Electrophysiol Clin 9 (2017) 1

# ECG features suggesting VT related to scar

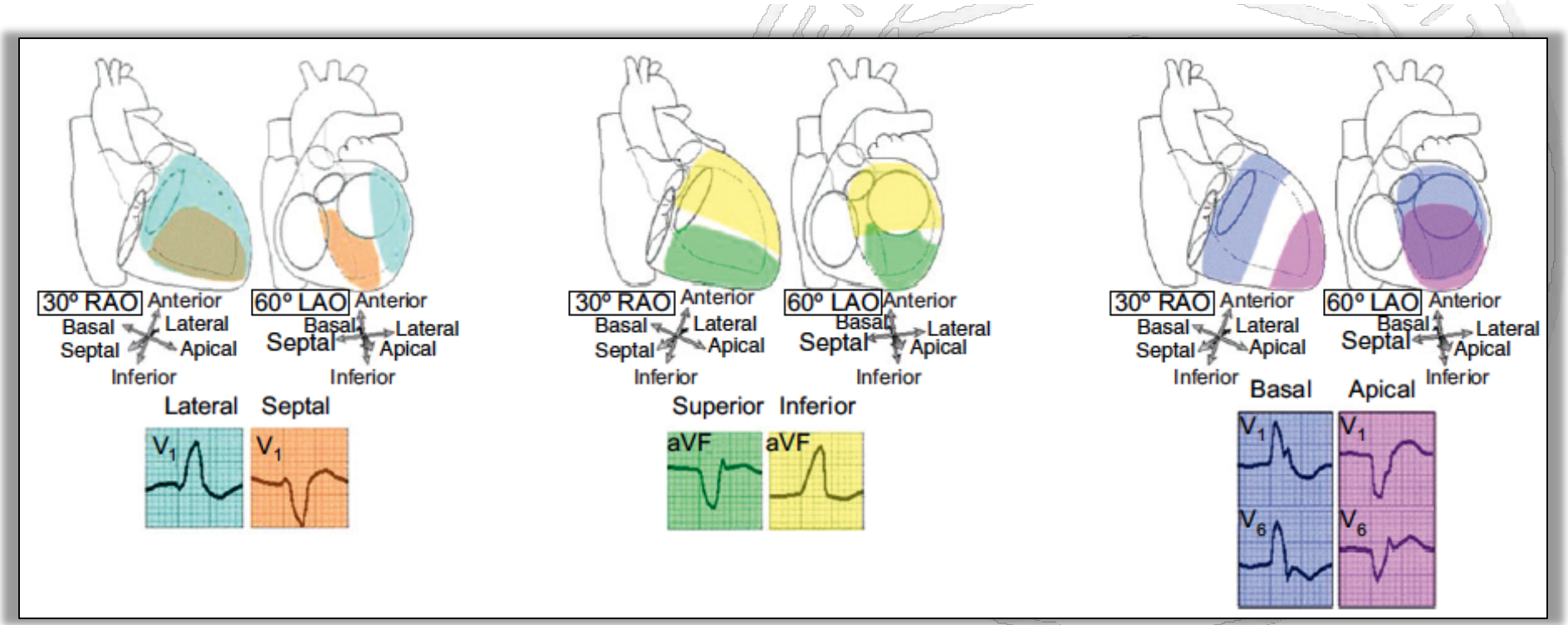
- *Presence of Q waves* (qR, QR or Qr) in related leads
  QS implies an electrical impluse moving away from the recording site
- *Notched or wide QRS* complexes
  Electrical activation is initiated in the viable myocytes with slow conduction
- *Low QRS voltage*
  Larger scar with less viable myocardium
- *Multiple morphologies* of monomorphic VT
- Paroxysmal sustained episodes



Benito B & Josephson ME. Rev Esp Cardiol 2012;65:939

# Locate the Reentrant Circuit Exit

*Localization of documented VT* ECG allows for *procedural planning*, particularly regarding *vascular access*, and for *guiding the initial mapping procedure*



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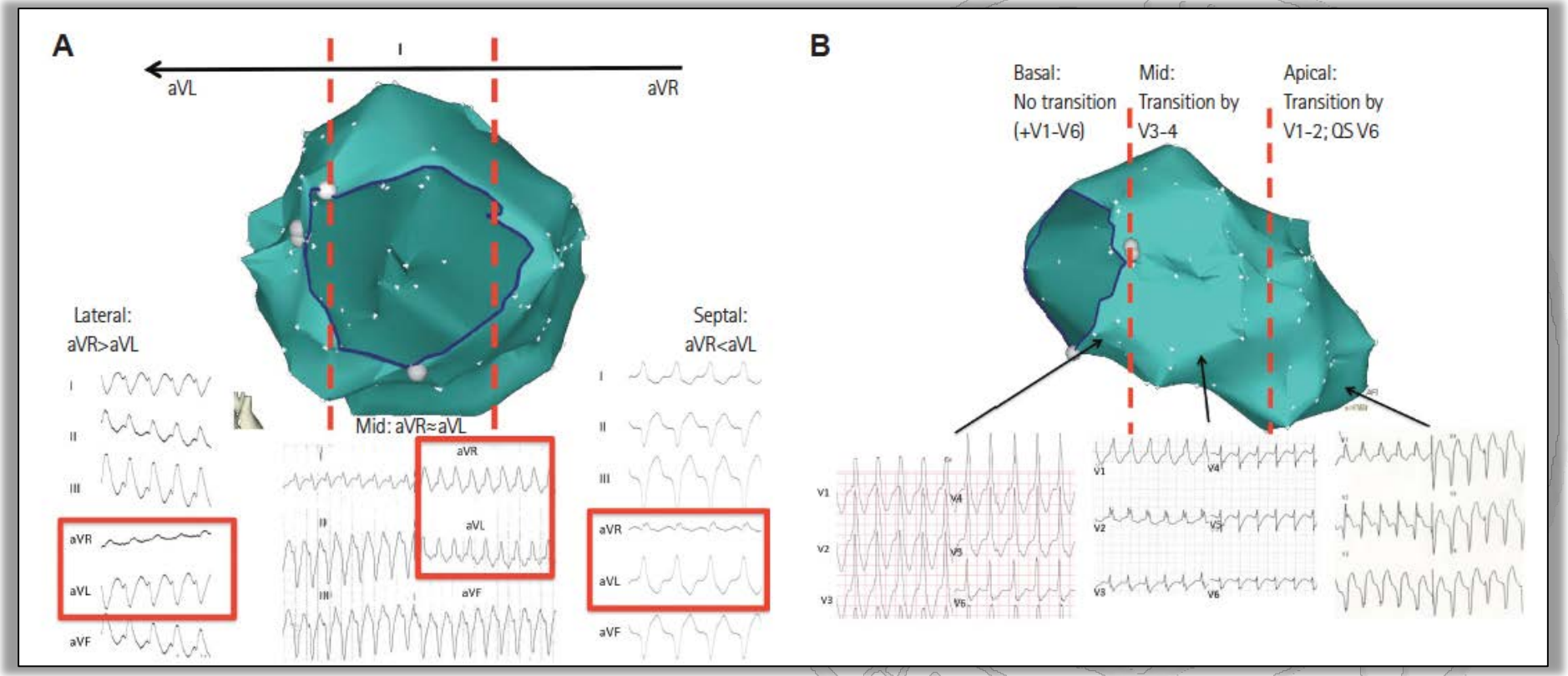
# Locate the Reentrant Circuit Exit






Nazer B & Gestenfeld EP. Korean Circ J 2014;44:201

# Relationship between the 12-lead ECG during VT & endocardial site of origin in patients with CAD

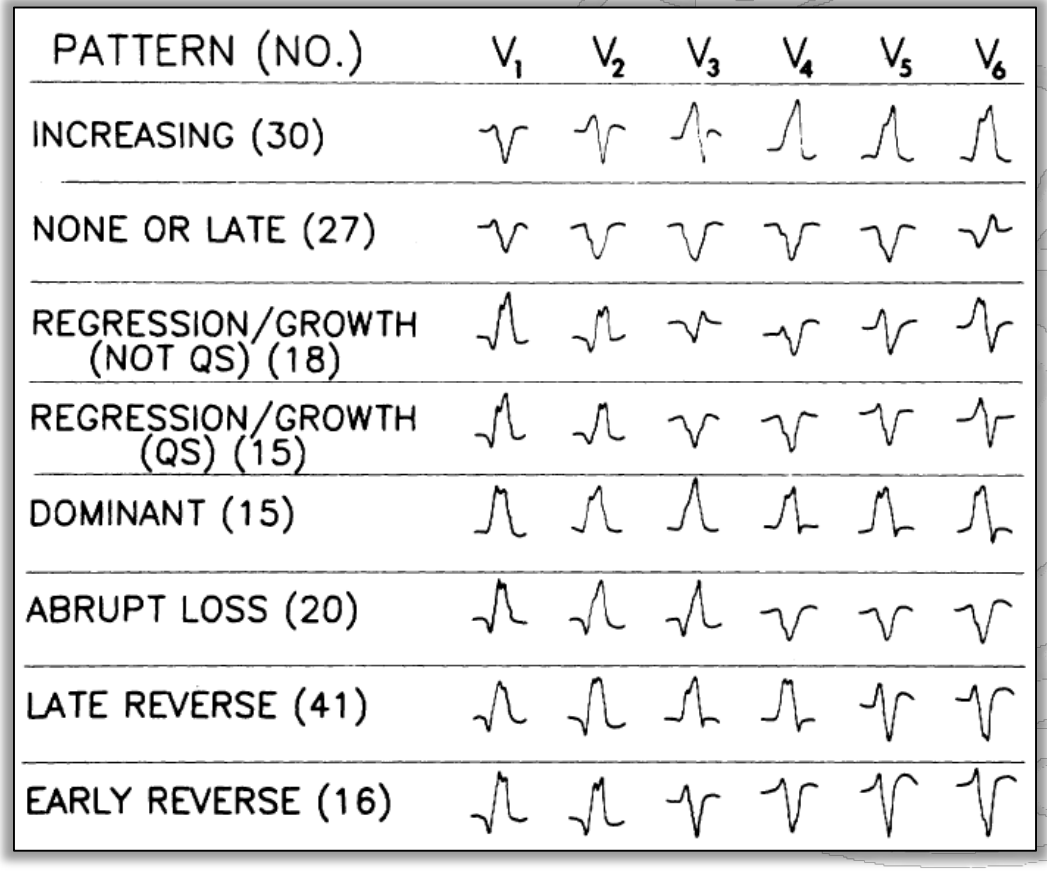
- Endocardial mapping: 182 VTs from 108 patients
- Catheter:surgical:both=154:85:57 VTs
- ECG, characterized by *4 features*
  1. Location of infarction
  2. BBB pattern
  3. Axis: four quadrants
  4. R wave progression pattern (RWP)
- Validation cohort: 110 VTs in 63 patients
  - ✓ 93% of the 65 VTs (*59% of the total number*) to which the algorithm could be applied



Miller JM et al. Circulation 1988;77:759

# Relationship between the 12-lead ECG during VT & endocardial site of origin in patients with CAD

## RWP patterns






Miller JM et al. Circulation 1988;77:759

# Inferior infarction-dependent VT

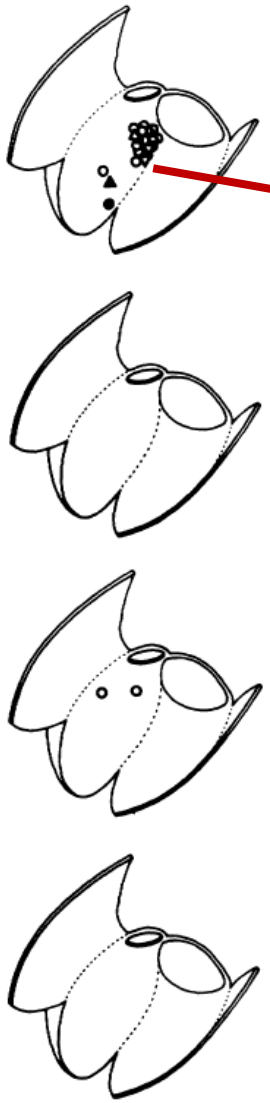
*LB VT*

Left superior

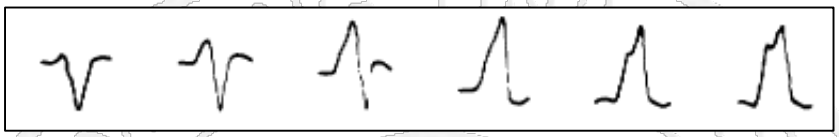
Right superior

Left inferior

Right inferior



Increasing



Inferobasal septum



Miller JM et al. Circulation 1988;77:759

# Inferior infarction-dependent VT

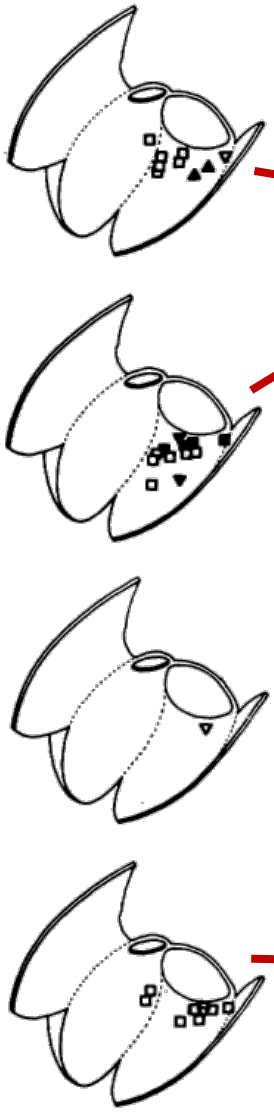
*RB VT*

Left superior

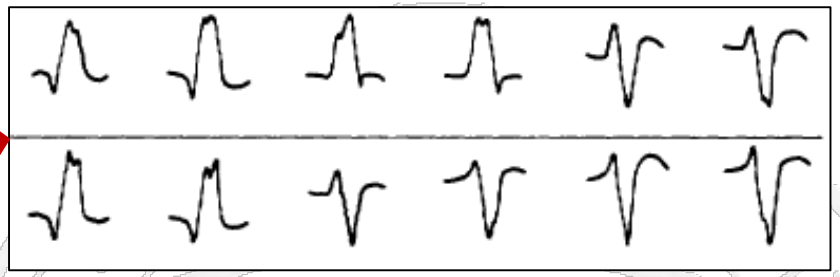
Right superior

Left inferior

Right inferior

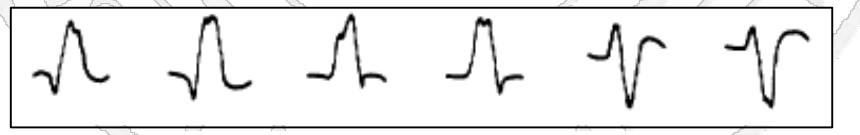


Reverse (either)



Inferobasal free wall

Reverse (late)



Inferobasal lateral wall



Miller JM et al. Circulation 1988;77:759

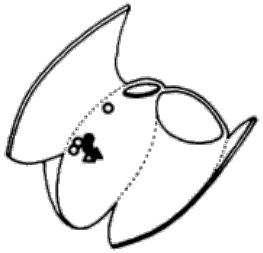
# Anterior infarction-dependent VT

*LB VT*

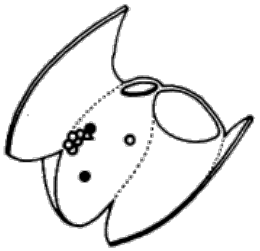
Left superior

Right superior

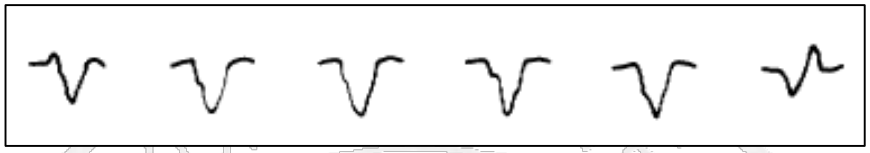
Left inferior



Right inferior



None or late



Inferoapical septum

Any pattern

Anteroapical septum

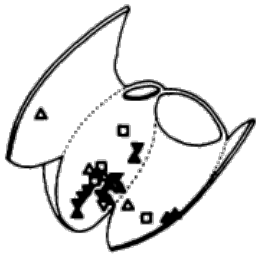


Miller JM et al. Circulation 1988;77:759

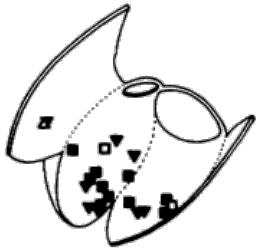
# Anterior infarction-dependent VT

*RB VT*

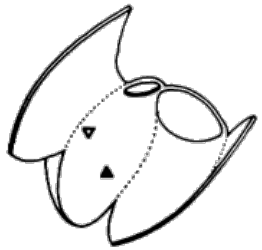
Left superior



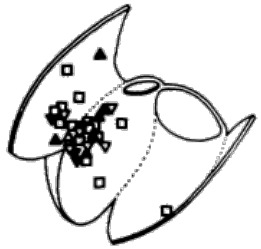
Right superior



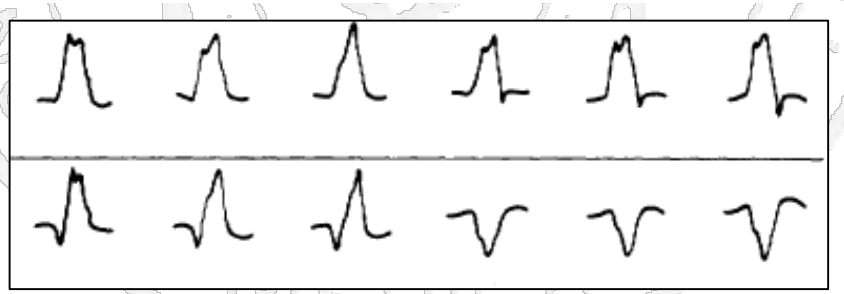
Left inferior



Right inferior



Dominant or abrupt loss



Anteroapical septum



Miller JM et al. Circulation 1988;77:759

# Relationship between the 12-lead ECG during VT & endocardial site of origin in patients with CAD

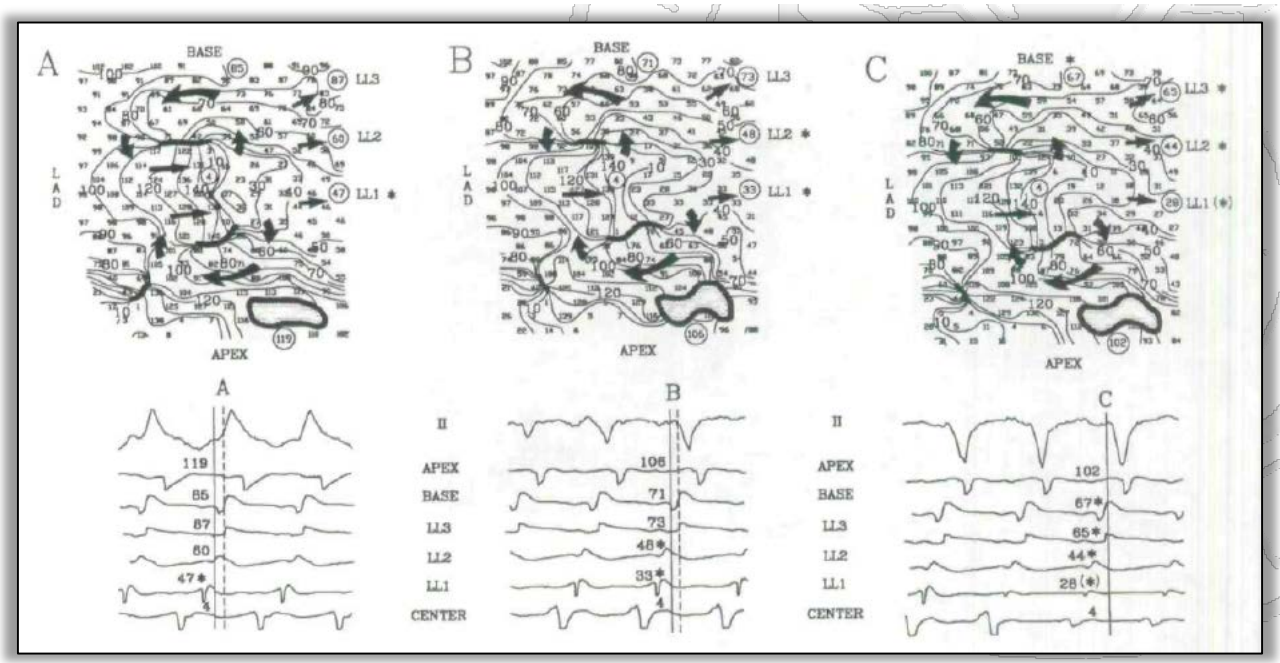
- the 12-lead ECG during VT contains *adequate information to specify a region of the LV endocardium* that is likely to contain the VT site of origin *in approximately half of all VTs in patients with a single prior infarction*



Miller JM et al. Circulation 1988;77:759

# Mechanism for spontaneous changes in QRS morphology ~ During Reentrant VT in a Canine Infarct Model

- Small *changes in conduction velocity* in the segment of the circuit, which *modified the length of the functional lines of block* resulted in a *shift of the exit*
  → QRS morphology changes






Schmitt H et al. JCE 2001;12;686

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# The value of catheter mapping during sinus rhythm to localize site of origin of ventricular tachycardia

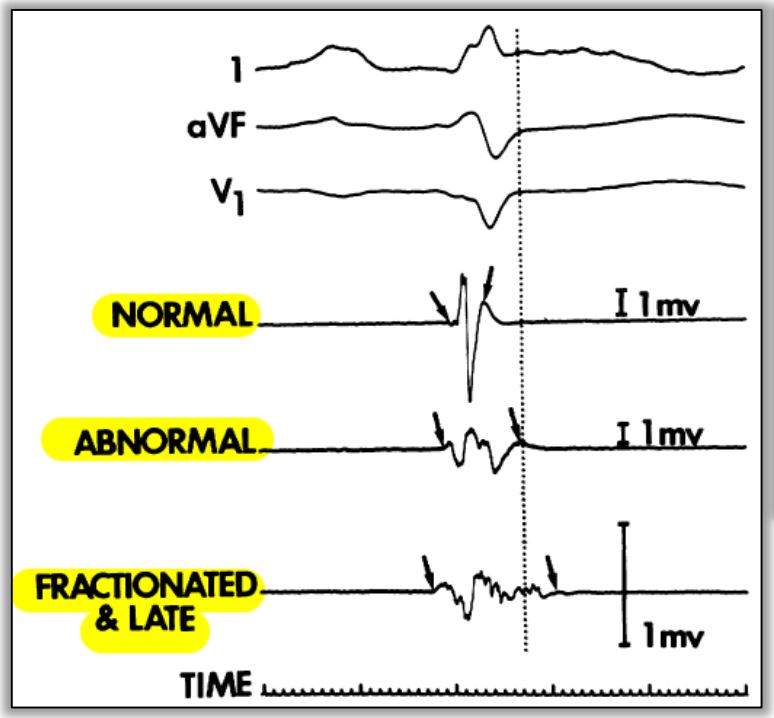
- Endocardial mapping with 5mm inter-electrode distance
- *52* patients with *102 monomorphic ischemic VT*
- ***Normal signal: ≥ 3 mV amplitude & ≤ 70ms duration***
  ***Normal amplitude/duration: ≥ 0.046***

✓ 546 EGMs (10.5/patient): 102 EGMs from site of origin
✓ Abnormal 312 EGMs (58%), normal 234 EGMs (42%)
✓ Mean abnormal amplitude: *1.4±0.9 mV*
✓ Mean abnormal duration: *93±40 ms*
✓ Mean abnormal amplitude/duration: *0.017±0.012*



*Cassidy DM, et al. Circ 1984a;69:1103*

# The value of catheter mapping during sinus rhythm to localize site of origin of ventricular tachycardia




**Comparison of electrograms of site of origin with those not of site of origin**

| | Site of origin | Non-site of origin | p value |
|---|---|---|---|
| Amplitude (mV) | 2.0 ± 2[A] | 3.6 ± 2.8 | <.001 |
| Duration (msec) | 88 ± 33 | 75 ± 27 | <.001 |
| Amplitude/duration ratio (mV/msec) | 0.027 ± 0.030 | 0.058 ± 0.055 | <.001 |



Cassidy DM, et al. Circ 1984a;69:1103

# The value of catheter mapping during sinus rhythm to localize site of origin of ventricular tachycardia

Although all values reached statistical significance, *much overlap between the groups was noted*

**Distribution of the 546 electrograms**

| Electrogram type | Site of origin | Non-site of origin | Total (%) of all electrograms |
|---|---|---|---|
| Normal | 14 | 220 | 234 (42) |
| Abnormal | 88 | 224 | 312 (58) |
| Fractionated | 10 | 37 | 47 (9) |
| Abnormal late | 26 | 54 | 80 (15) |
| Fractionated late | 8 | 18 | 26 (5) |
| Longest | 16 | 36 | 52 (10) |



Cassidy DM, et al. Circ 1984a;69:1103

# The value of catheter mapping during sinus rhythm to localize site of origin of ventricular tachycardia

We found that electrograms from *the site of origin were of significantly lower amplitude and longer duration*; however, because such an overlap occurred with electrograms that were not from sites of origin, this *does not serve as a useful clinical marker* ~~ *None of these types* possessed the ability to *reliably localize the site of origin* of ventricular tachycardia.

We therefore conclude that *endocardial catheter mapping during sinus rhythm is not useful as a guide* in localized surgical therapy of ventricular tachycardia



Cassidy DM, et al. Circ 1984a;69:1103

# Catheter Ablation of Ventricular Tachycardia After Myocardial Infarction: Relation of Endocardial Sinus Rhythm Late Potentials to the Reentry Circuit

- 24 patients with ischemic VT
- *103 sites of EGM* during sinus rhythm & attempted to terminate VT by RF
- *Late potential (LP)* present at 34 sites (33%)

| | Total Sites | LP Positive Sites | LP Negative Sites | p Value |
|---|---|---|---|---|
| Pace mapping S-QRS (ms) | | | | < 0.0001 |
| <41 | 9 | 0 | 9 (100) | |
| 41–80 | 41 | 7 (17) | 34 (83) | |
| >80 | 31 | 19 (61) | 12 (39) | |
| Reentry circuit site classification | | | | < 0.0001* |
| Exit | 13 | 3 (23) | 10 (77) | |
| Central/proximal | 21 | 15 (71) | 6 (29) | |
| Inner loop | 13 | 2 (15) | 11 (85) | |
| Outer loop | 17 | 1 (6) | 16 (94) | |
| Adjacent bystander | 12 | 9 (75) | 3 (25) | |
| Remote bystander | 27 | 4 (15) | 23 (85) | |
| Isolated potential in VT | | | | 0.32 |
| Isolated potential | 24 | 10 (43) | 14 (57) | |
| No isolated potential | 79 | 24 (31) | 55 (69) | |
| Effect of RF on VT | | | | 0.004 |
| VT terminated | 37 | 20 (54) | 17 (46) | |
| VT not terminated | 66 | 14 (21) | 52 (79) | |



Harada T, et al. J Am Coll Cardiol 1997;30:1015

# Catheter Ablation of Ventricular Tachycardia After Myocardial Infarction: Relation of Endocardial Sinus Rhythm Late Potentials to the Reentry Circuit

## *Conclusions*

Although sites with sinus rhythm late potentials often participate in VT reentry circuits, *many reentry circuit sites do not have late potentials*. *Late potentials can also arise from bystander regions*. Late potentials may help identify abnormal regions in sinus rhythm but *cannot replace mapping during induced VT to guide ablation*



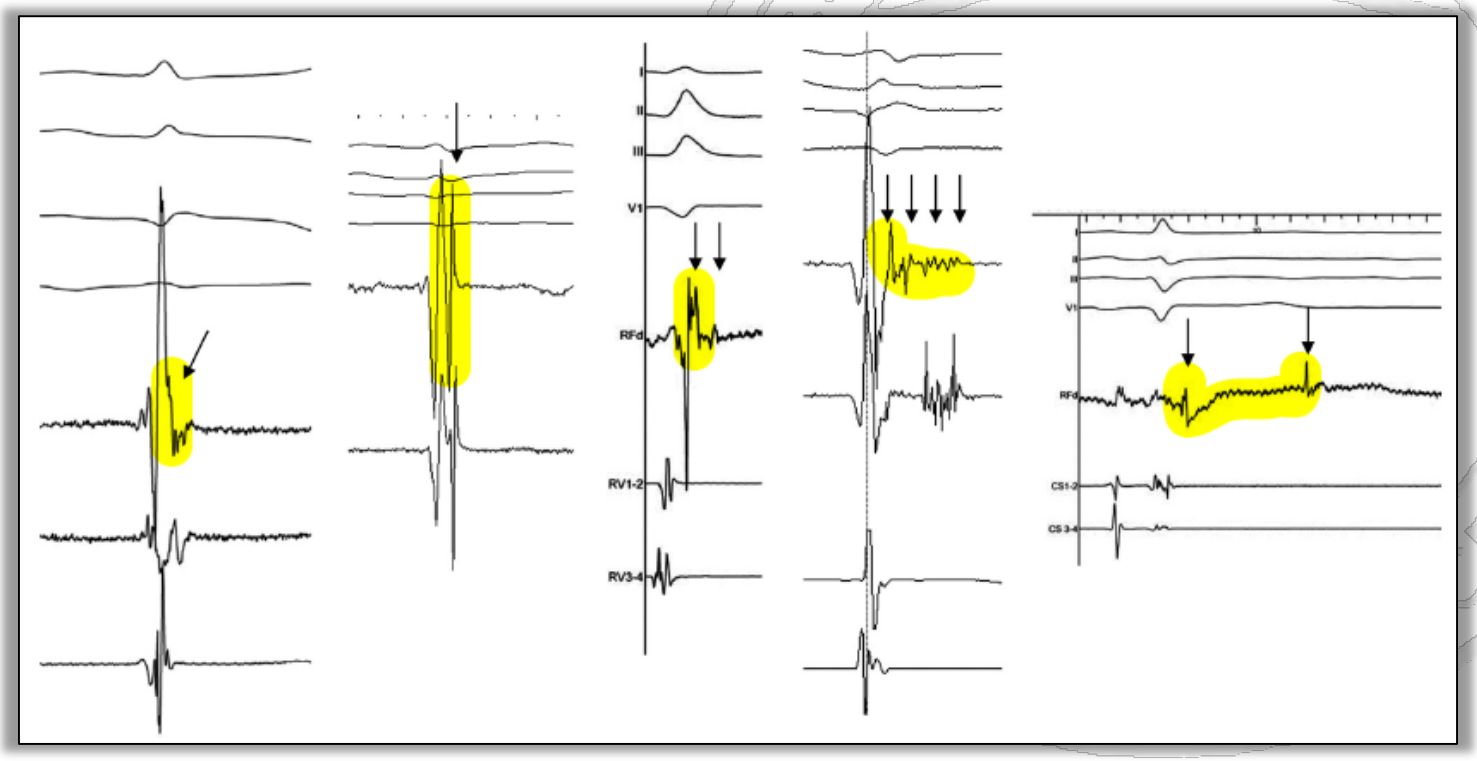
*Harada T, et al. J Am Coll Cardiol 1997;30:1015*

# Elimination of Local Abnormal Ventricular Activities

## A New End Point for Substrate Modification in Patients With Scar-Related Ventricular Tachycardia

## LAVAs (Local Abnormal Ventricular Activities)

- *sharp high-frequency ventricular potentials*, possibly of *low amplitude*, *distinct from the far-field ventricular electrogram*






Jais P, et al. Circulation 2012;125:2184

# Elimination of Local Abnormal Ventricular Activities

## A New End Point for Substrate Modification in Patients With Scar-Related Ventricular Tachycardia

- LAVAs were recorded in *67/70 patients (95.7%)*
- LAVAs *occupied 16%* (39±32 $cm^2$ of the 245±174 $cm^2$) of the LV surface

| | All Patients (n=70) | LAVAs Eliminated (n=47) | LAVAs Not Eliminated (n=20) | *P** |
|---|---|---|---|---|
| LAVA endocardial amplitude, mV | 0.11 (0.08–0.22) | 0.12 (0.08–0.21) | 0.14 (0.10–0.29) | 0.41 |
| LAVA epicardial amplitude, mV | 0.37 (0.20–0.60) | 0.39 (0.20–0.70) | 0.22 (0.18–0.50) | 0.38 |
| Far-field ventricular endocardial amplitude, mV | 0.20 (0.10–0.50) | 0.18 (0.10–0.60) | 0.25 (0.10–0.43) | 0.80 |
| Duration of far-field ventricular signal, ms | 60 (50–83) | 61 (50–80) | 60 (50–108) | 0.66 |
| Endocardial far-field ventricular to LAVA delay, ms | 80 (60–110) | 90 (70–115) | 70 (55–100) | 0.13 |
| Endocardial QRS to LAVA delay, ms | 0 (0–40) | 20 (0–40) | 0 (0–40) | 0.50 |



Jais P, et al. Circulation 2012;125:2184

# Elimination of Local Abnormal Ventricular Activities

## A New End Point for Substrate Modification in Patients With Scar-Related Ventricular Tachycardia

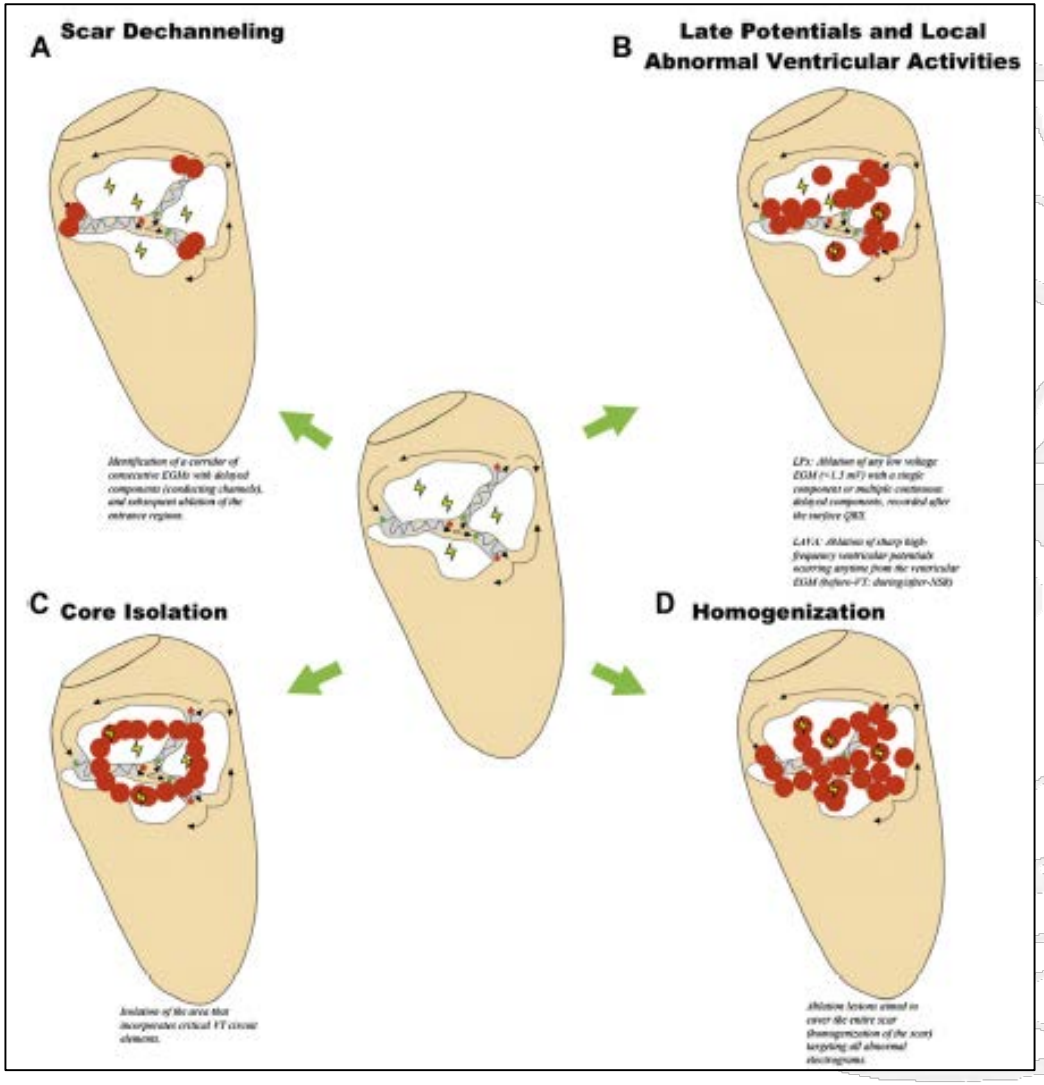
In multivariate analysis, *LAVA elimination was independently associated with a reduction in recurrent VT or death* (hazard ratio, 0.49; 95% confidence interval, 0.26–0.95; P 0.035) during long-term follow-up (median, 22 months).

*Conclusions* — LAVAs can be identified in most patients with scar-related VT. *Elimination of LAVAs is feasible and safe* and is associated with superior survival free from recurrent VT



Jais P, et al. Circulation 2012;125:2184

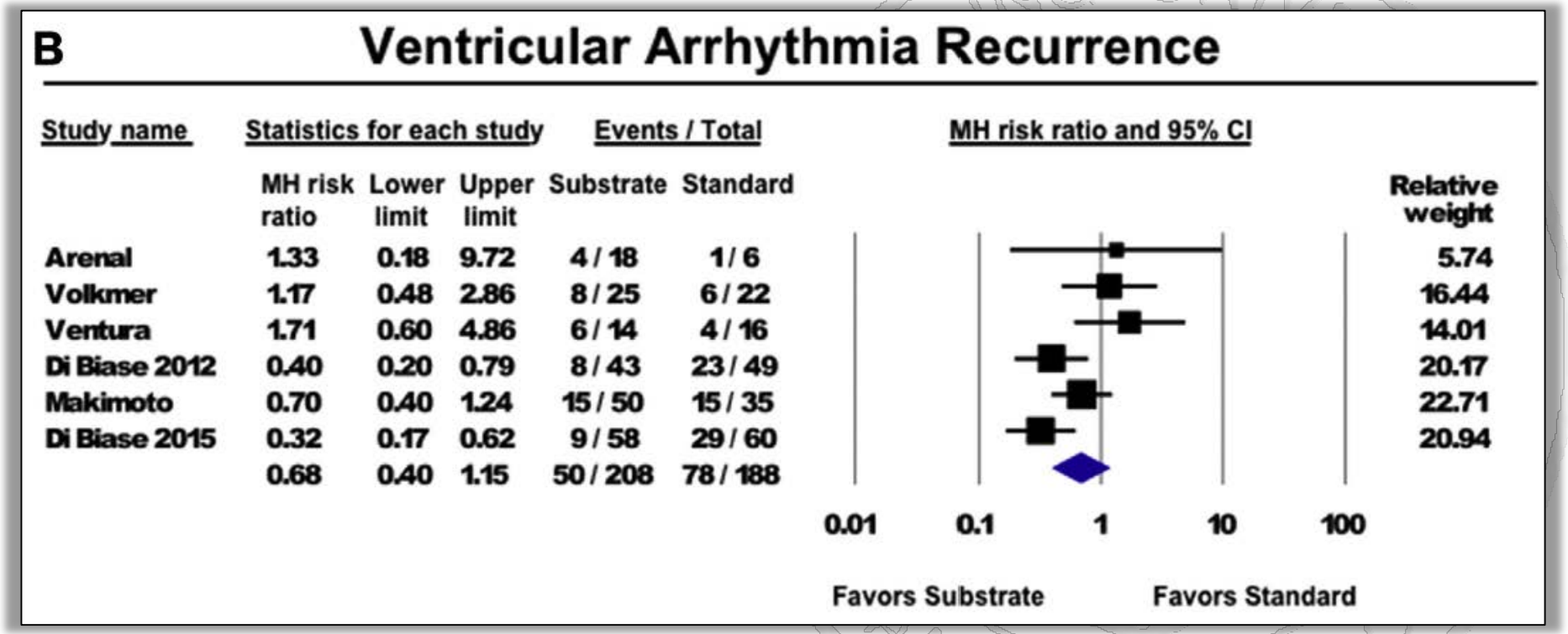
# Substrate Ablation of VT



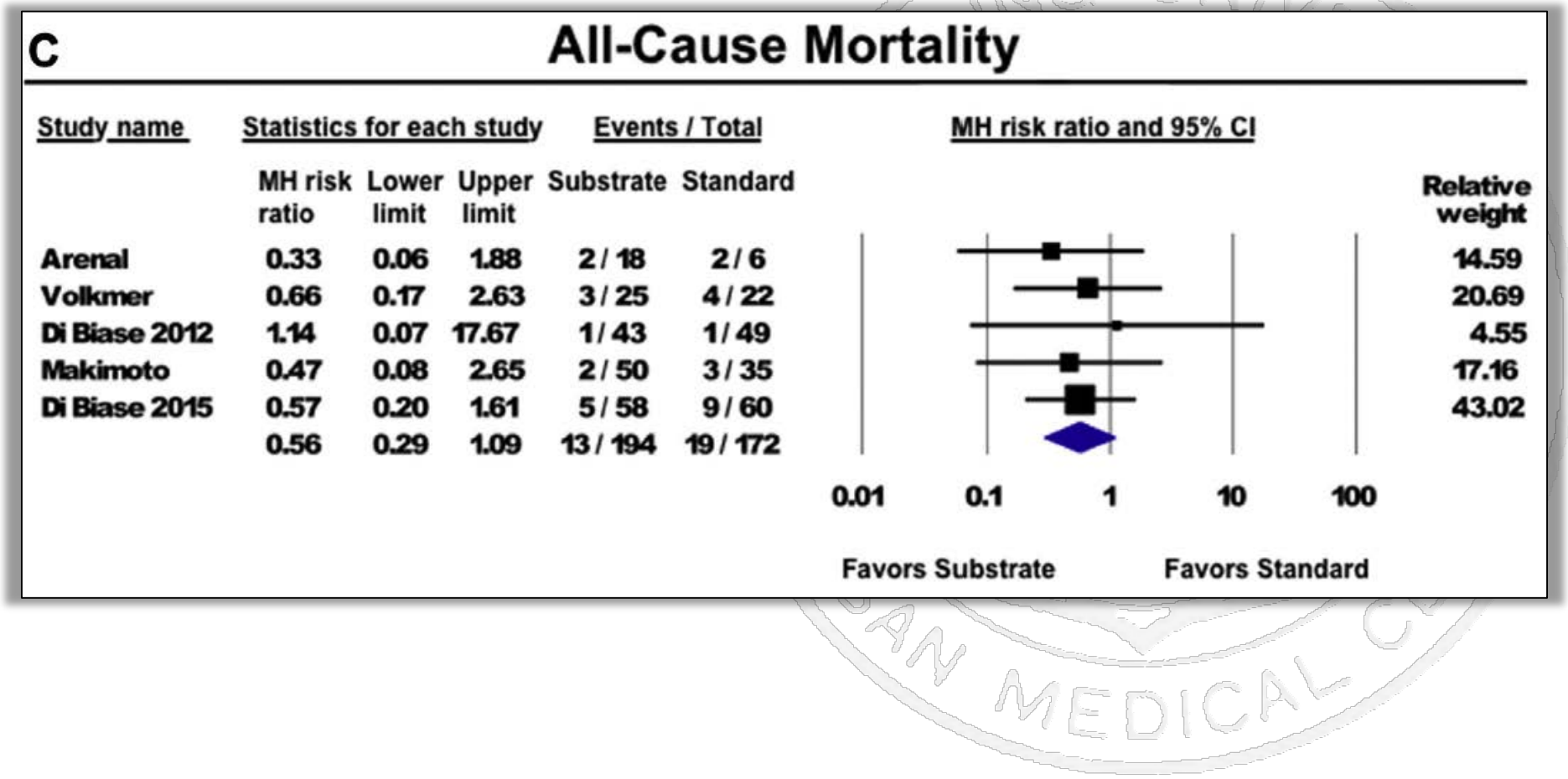



Briceño DF, et al. Card Electrophysiol Clin 9 (2017) 81

# Substrate Ablation of VT



# Substrate Ablation of VT






Briceño DF, et al. Card Electrophysiol Clin 9 (2017) 81

# Electrograms during sinus rhythm

- Abnormal electrogram, late potential, & LAVA can help to *identify the possible arrhythmogenic area* of VT circuit

- Substrate mapping itself could not help to define the reentrant circuit

# Response to overdrive pacing

- *Overdrive pacing* can aid in choosing target site for ablation
  - ✓ By helping determine *tachycardia mechanism*
  - ✓ By helping *validate putative ablation sites*

- *Ablation target*
  - Focal tachycardia: *presystolic potential* (late diastolic)
  - Microreentry: *long fragmented diastolic potential*
  - Macroreentry: *mid-diastolic potential*

# Entrainment

To declare entrainment is present, fusion must be unequivocally demonstrated (except, microreentry)

➢ *FUSION* is *NOT*

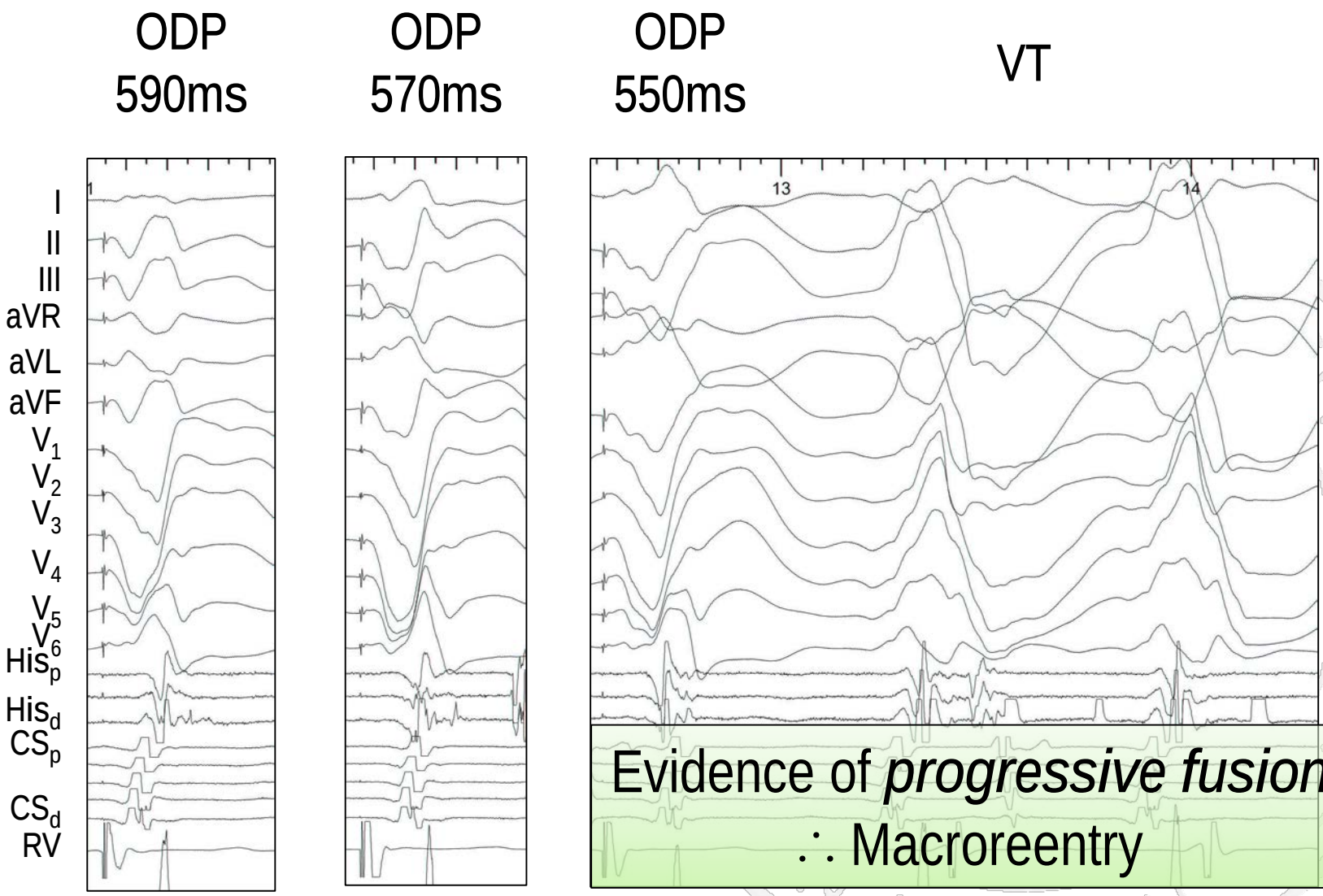
- *Mere capture* with overdrive pacing
- Overdrive pacing followed by *tachycardia termination*
- Overdrive pacing followed by *change in tachycardia*

# Entrainment

To declare entrainment is present, fusion must be unequivocally demonstrated (except, microreentry)

➢ *FUSION* is *PRESENT* when

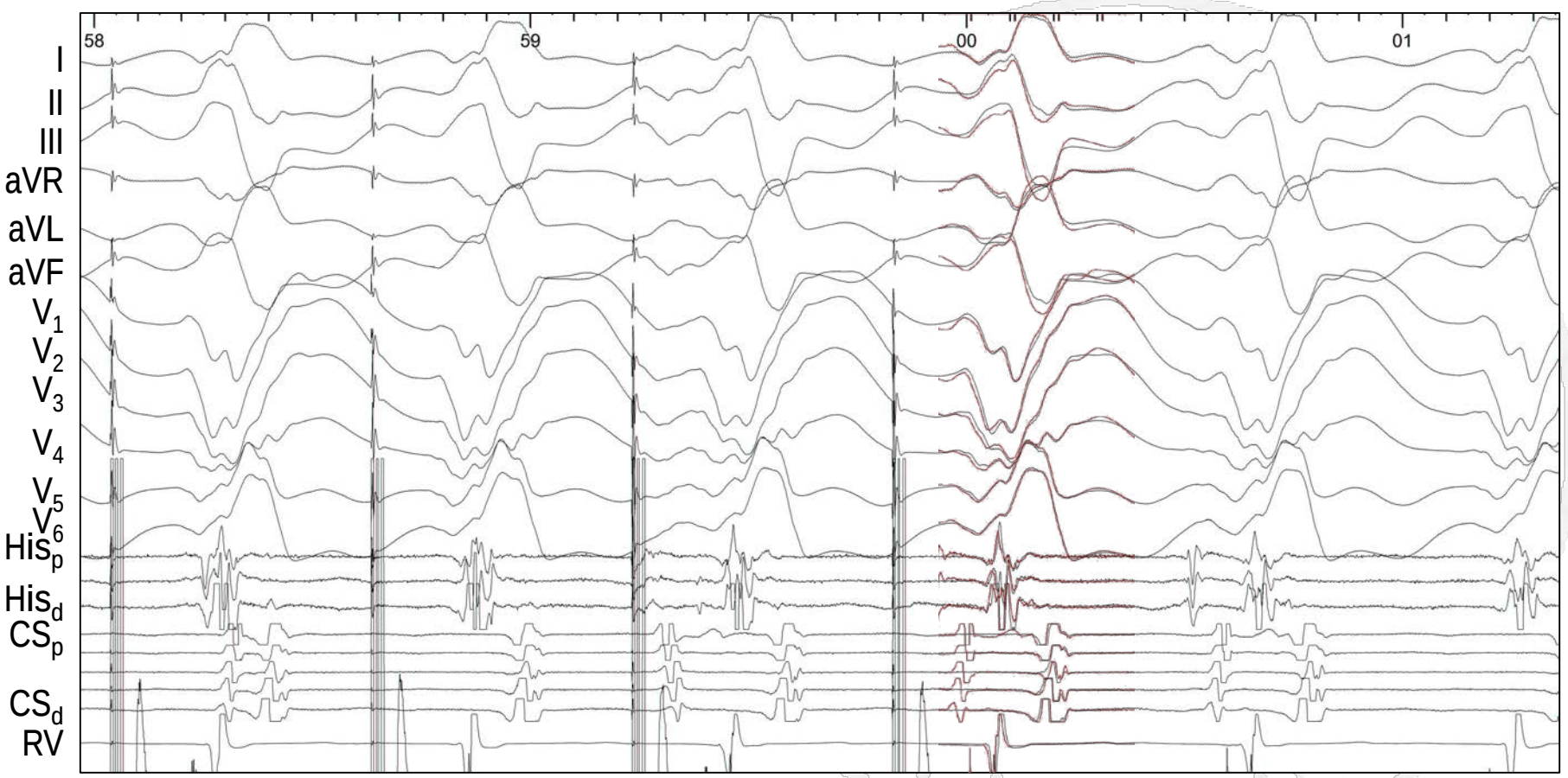
- A clear *blend* of *fully paced* + *full tachycardia* complexes
- Observe *stimulus artifact after onset of accelerated complex*
  - ✓ evidence that the tachycardia wavefront have exited from the circuit
- *Progressive fusion*: Show graded change in activation at different paced rates


ODP
590ms
ODP
570ms
ODP
550ms
VT
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
Hisp
Hisd
CSp
CSd
RV
1
13
14
Evidence of progressive fusion
∴ Macroreentry

# Entrainment Lingo

- Entrainment with *Manifest fusion*
- Entrainment with *Concealed fusion*
  - ✓ Other entrainment criteria are met but no fusion is seen (pacing looks exactly like tachycardia) due to *pacing in a protected diastolic zone*
  - ✓ *Pacing from the same site during sinus rhythm could produce a different morphology* as long as antidromic conduction through the protected area can occur

# Overdrive pacing: *Concealed fusion*



# Entrainment Mapping

- Simple demonstration of *entrainment alone does not indicate the location* of the pacing site relative to the reentry circuit

- *Other parameters* are needed to localize the circuit
  - Timing of EGM to QRS: systolic vs. diastolic
  - QRS configuration during entrainment
  - PPI after entrainment
  - S-QRS & EGM-QRS and its relationship to the VT CL

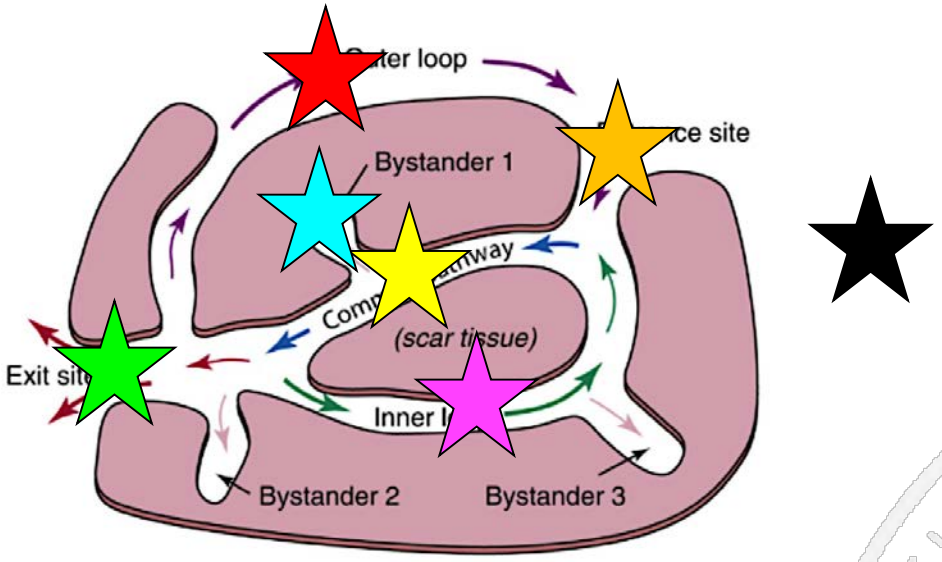
# Entrainment Mapping

| Pacing from the Sites *Outside* the Reentrant Circuit |
|---|
| • Manifest fusion on surface ECG or intracardiac recording, or both |
| • PPI-TCL > 30 msec |
| • Stimulus-exit interval > electrogram-exit interval |
| **Pacing from the Sites *Inside* the Reentrant Circuit** |
| • Manifest fusion on surface ECG or intracardiac recording, or both |
| • PPI-TCL < 30 msec |
| • Stimulus-exit interval = electrogram-exit interval (± 20 msec) |
| **Pacing from a *Protected Isthmus* Inside the Reentrant Circuit** |
| • Concealed fusion |
| • PPI-TCL < 30 msec |
| • Stimulus-exit interval = electrogram-exit interval (± 20 msec) |

# Entrainment Mapping

## Entrainment with concealed fusion

- *PPI* > *TCL* : *bystander* of diastolic corridor
- **PPI ≈ TCL** : within diastolic corridor
  - S-EGM < 0.25 X diastolic interval : exit site
  - S-EGM 0.25 to 0.75 X diastolic interval : mid-corridor
  - S-EGM > 0.76 X diastolic interval : entrance site



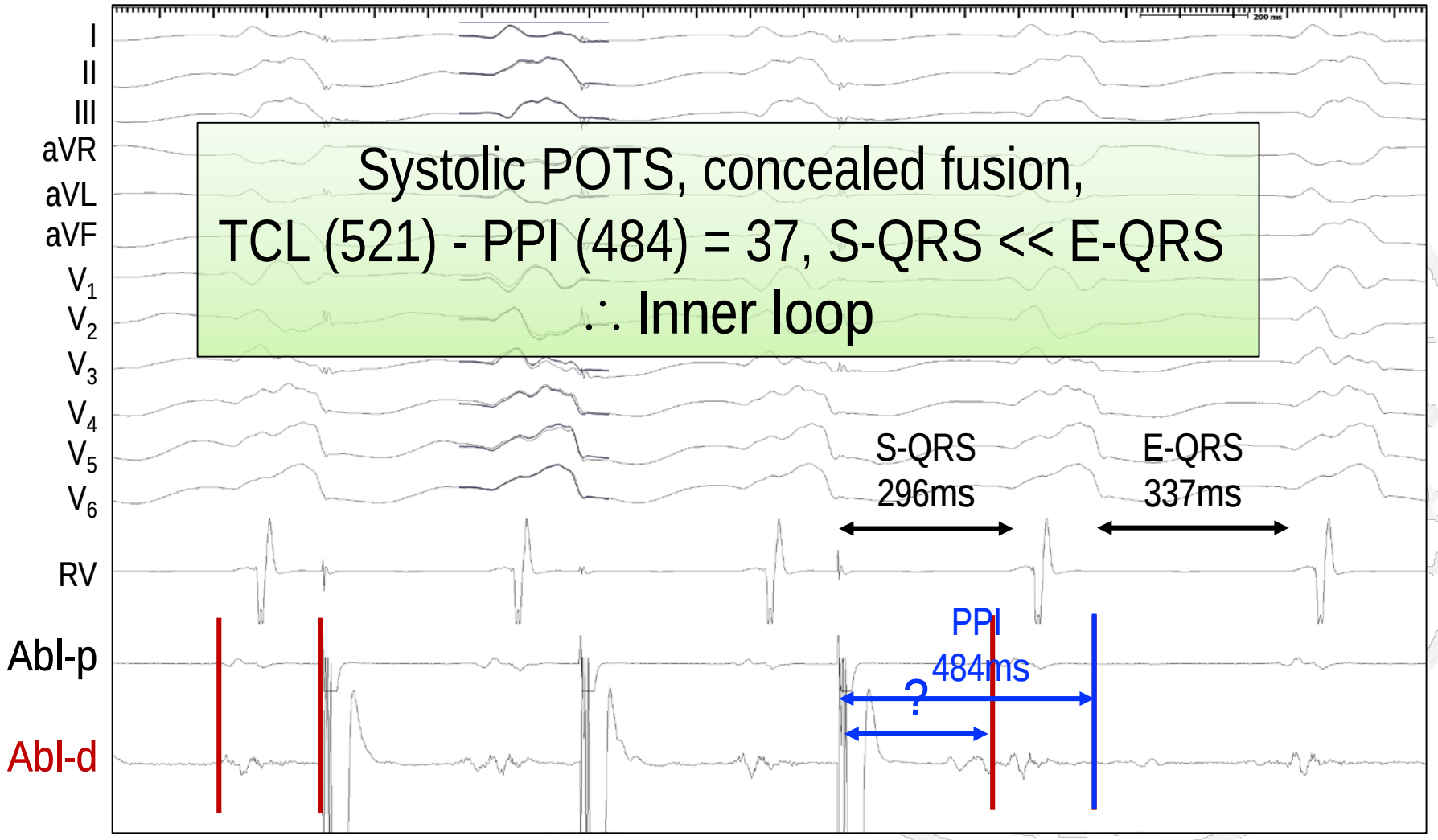

| Site of stimulation | Fusion | S-QRS | PPI |
|---|---|---|---|
| Central isthmus | Concealed | = E-QRS in VT (30~70% of TCL) | = TCL |
| Exit site | Concealed | = E-QRS in VT | = TCL |
| Entrance site | Concealed | = E-QRS in VT | = TCL |
| Inner loop | Concealed | < E-QRS in VT | = TCL |
| Bystander | Concealed | > E-QRS in VT | > TCL |
| Outer loop | Manifest | < E-QRS in VT | = TCL |
| Away from the circuit | Manifest | varies | > TCL |



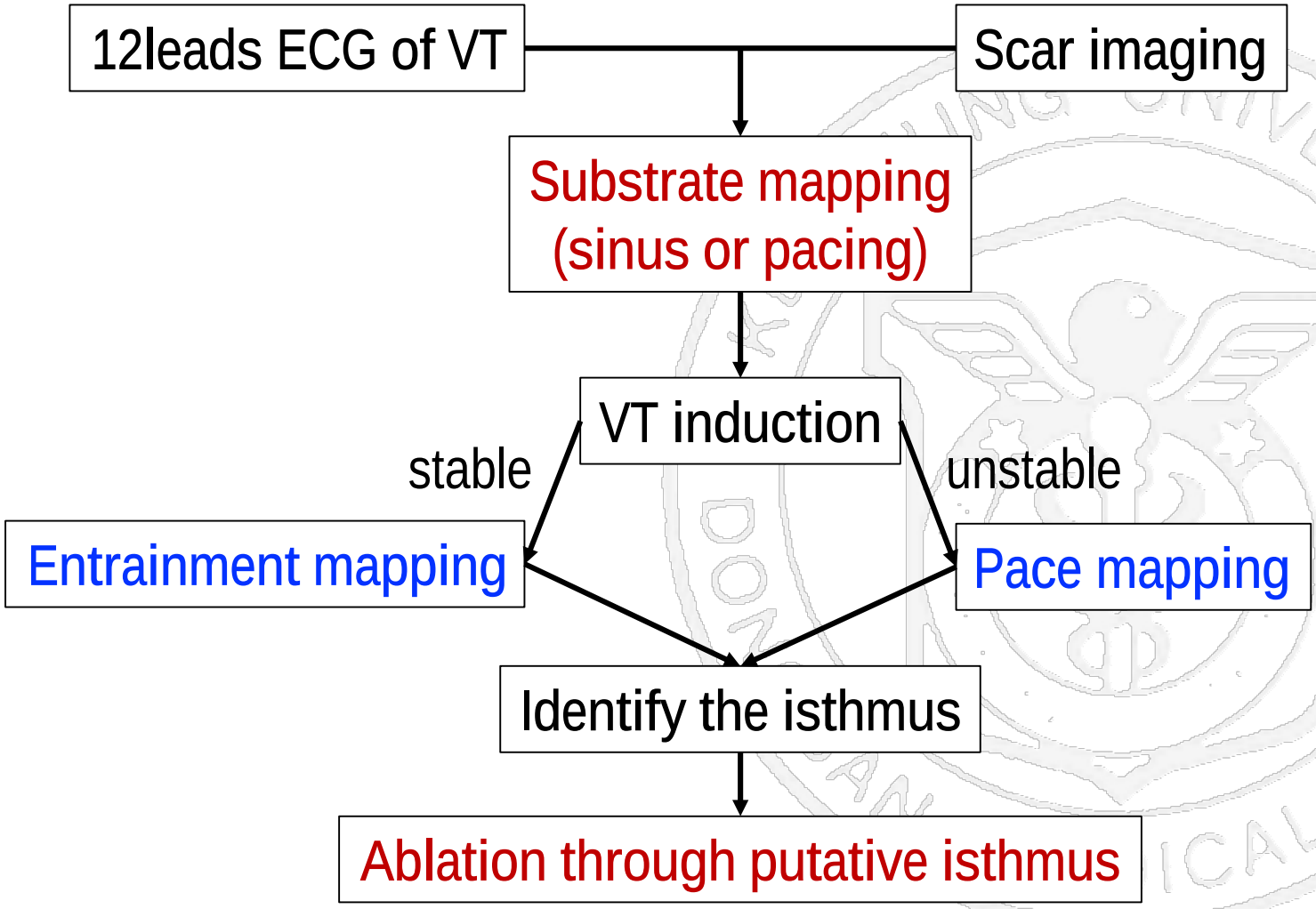
Benito B & Josephson ME. Rev Esp Cardiol 2012;65:939

# Overdrive pacing: *Concealed fusion*

TCL: 521 ms



# My Approach


12leads ECG of VT
Scar imaging
Substrate mapping
(sinus or pacing)
VT induction
stable
unstable
Entrainment mapping
Pace mapping
Identify the isthmus
Ablation through putative isthmus

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# Thank You for Your Attention !

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